**TECHNICAL REPORT**
**NATICK/TR-95/012**

AD_____

# THERMAL OPTIMIZATION OF FLAMELESS RATION HEATERS

**By**
**Satish G. Kandlikar**

**December 1994**

19950109 042

DTIC
SELECTED
JAN 11 1995
B

**FINAL REPORT**
**June 1990 - August 1990**

**Approved for Public Release; Distribution Unlimited**

**UNITED STATES ARMY**
**RESEARCH, DEVELOPMENT AND ENGINEERING CENTER**
**NATICK, MASSACHUSETTS 01760-5000**

**SUSTAINABILITY DIRECTORATE**

## DISCLAIMERS

The findings contained in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

## DESTRUCTION NOTICE

# REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE<br>**December 1994** | 3. REPORT TYPE AND DATES COVERED<br>Final June 1990 to August 1990 |
|---|---|---|

**4. TITLE AND SUBTITLE**

THERMAL OPTIMIZATION OF FLAMELESS RATION HEATERS

**6. AUTHOR(S)**

Satish G. Kandlikar

**5. FUNDING NUMBERS**

Contract No.
DAAL03-86-D-6002

Delivery No.
#1979

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

U.S. Army Natick RD&E Center
ATTN: SATNC-WEA
Natick, MA 01760

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**NATICK/TR-95/012**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**

Approved for Public Release; Distribution Unlimited

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** (Maximum 200 words)

A thermal simulation program utilizing finite difference technique is developed to analyze the transient heat transfer problem of heating the Meals-Ready-to Eat (MREs) using Flameless Ration Heaters. The simulation program is employed in evaluating the effects of changing various parameters on the thermal performance. It is suggested that the results from the program be checked with experiments conducted under controlled conditions in which the heater heat generation rate and the temperature profile in the food are carefully monitored under different operating conditions.

| 14. SUBJECT TERMS | | | 15. NUMBER OF PAGES<br>**54** |
|---|---|---|---|
| THERMAL ANALYSIS<br>HEAT TRANSFER<br>FLAMELESS | MRE(MEAL, READY-TO-EAT)<br>FLAMELESS RATION HEATER (FRH)<br>COMPUTER PROGRAMS<br>FLAMELESS BURNERS | HEATING<br>HOT MEALS<br>SELF HEATING<br>RATIONS | 16. PRICE CODE |

| 17. SECURITY CLASSIFICATION OF REPORT<br>UNCLASSIFIED | 18. SECURITY CLASSIFICATION OF THIS PAGE<br>UNCLASSIFIED | 19. SECURITY CLASSIFICATION OF ABSTRACT<br>UNCLASSIFIED | 20. LIMITATION OF ABSTRACT<br>SAR |
|---|---|---|---|

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

# CONTENTS

iii

# LIST OF FIGURES

# PREFACE

# ACKNOWLEDGMENTS

# NOMENCLATURE

A - surface area in contact between the heater and the food pouch

$c_p$ - specific heat , J/kg-K

i - node number

j - i + 1 node number

k - thermal conductivity, W/m-$^\circ$C

n - time step number

$R_{i,j}$ - thermal resistance between nodes i and j, $^\circ$C

T - temperature, $^\circ$C

$\Delta t$ - time step, sec

w - thickness, m

# SUMMARY

A thermal simulation program utilizing finite difference technique was developed to analyze the transient heat transfer problem of heating the Meals-Ready-to-Eat (MRE's) using Flameless Ration Heaters (FRH). The simulation program was employed in evaluating the effect of changing various parameters on the thermal performance. The results indicate that the heating time could be further reduced by increasing the heater area in contact with the food pouch, and by improving the carton insulation. It is suggested that the results for the optimized geometry be checked with experiments conducted under controlled conditions in which the heater heat generation rate and the temperature profile in the food are carefully monitored under different operating conditions. Based on the experience of the theoretical simulation and experimental work, the scope for future work has been outlined.

# THERMAL OPTIMIZATION OF FLAMELESS RATION HEATERS

## 1. INTRODUCTION

The Flameless Ration Heater (FRH) is used by soldiers for heating the Meals-Ready-to-Eat (MRE) packaged in a plastic pouch. The FRH consists of a heating pad which is activated by water to start a controlled oxidation reaction of Magnesium. The specification and composition of heater element is as follows:

Weight:          20 gms.

Size:          11.4 cm x 8.9 cm x 0.3 cm thick
               (4.5" x 3.5" x 0.12" thick)

Composition:   Mg powder  -   40%
               Fe powder   -   10%
               Salt (NaCl) - 3%
               Other materials - 47%
               (Includes binder, wetting agent, fumed silica
               and other inert materials)

Amount of Water Required to Activate - 56 gms. (2 ozs.)

With the specified amount of water, the FRH generates 123.4 kJ (117 BTU) of thermal energy. The heat released during the reaction is utilized in heating the MRE pouch. The technical characteristics of the heater related to its thermal performance are as follows:

2

* Flameless Ration Heater should raise the temperature of a 227 gms (8 ozs.) packet of unfrozen Meals-Ready-to-Eat by 44.4 °C (80 °F) in less than 20 minutes (preferably 10 mins or less).

* Flameless Ration Heater should be able to perform as stated above over an ambient temperature range from -32 °C to 43 °C (-25 °F to 110 °F).

The present work is aimed toward simulating the thermal performance of the heating process and evaluating the effect of varying different parameters on the performance.

## 2. OBJECTIVES OF PRESENT WORK

The objectives of the present work are as follows:

a) Develop a computer program to simulate the thermal performance of the Flameless Ration Heater during the heating process.

b) Conduct experiments to obtain the thermal performance of the heating process under controlled conditions to verify the computer model predictions and identify any significant departures from the assumed system behavior.

c) Identify the system parameters which have the greatest influence on the heat transfer performance of the heater. Conduct a parametric investigation using the simulation program to study the effect of varying these parameters for optimizing the performance of the heating process.

The work undertaken here will be helpful in optimizing the thermal performance of the heater. The understanding of the heating process will be useful in the design of heaters for other applications such as heaters for individual tray packs.
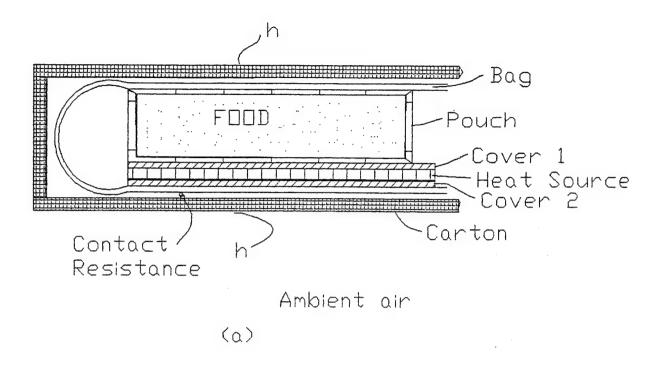
3

# 3. THEORETICAL ANALYSIS

## 3.1 Assumptions

A schematic of the Flameless Ration Heater with a food pouch (Meal-Ready-to-Eat) is shown in Fig. 1a. The transient heat conduction problem is analyzed with the following assumptions:

**a)** The heat transfer through the food pouch is one-dimensional.

**b)** The heat generation in the heater starts as a result of a chemical reaction which is initiated after a certain time delay after adding the water to the heater bag. The heater surface temperature is assumed to reach a specified temperature after the reaction is initiated.

**c)** The heat generated in the heater is assumed to be conducted away from both sides of the heater.

**d)** The contact resistances between the food pouch and the heater cover, and between the heater pad and the cover are assumed to be negligible due to the presence of water.

The above assumptions were made on the basis of the information available at the beginning of the project. The validity of these assumptions was checked by conducting experiments discussed in Section 5.

## 3.2 Finite Difference Formulation

The transient heat conduction problem is solved by a one-dimensional finite difference formulation. The location of the nodes are shown in Fig. 1b. The food pouch was divided into ten nodes, and the thermal resistances between the heater and the pouch,
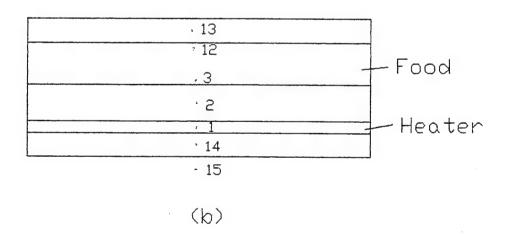
4

Figure 1. a) Schematic of a Flameless Ration Heater with MRE pouch.

b) Location of nodes in the heater assembly for finite difference analysis

heater and the surroundings and the pouch and the surroundings were lumped into three individual nodes.

The Crank-Nicholson formulation (Burden et al., 1980) is employed to obtain the following finite difference equations.

Internal nodes: $i = 2\text{-}12$, time step $n$ to $n+1$

$$m_i \, c_{p,i} \, (T_i^{n+1} - T_i^n) = \{(1/R_{i,(i-1)})[(T_{i-1}^{n+1} - T_i^{n+1}) + (T_{i-1}^n - T_i^n)]/2$$

$$+ \, (1/R_{i,(i+1)})[(T_{i+1}^{n+1} - T_i^{n+1}) + (T_{i+1}^n - T_i^n)]/2\} \, \Delta t \tag{1}$$

Node 13

$$m_{13} \, c_{p,13} \, (T_{13}^{n+1} - T_{13}^n) = \{(1/R_{13,1})[(T_1^{n+1} - T_{13}^{n+1}) + (T_1^n - T_{13}^n)]/2$$

$$+ \, (1/R_{13,15})[(T_{15}^{n+1} - T_{13}^{n+1}) + (T_{15}^n - T_{14}^n)]/2\} \, \Delta t \tag{2}$$

Node 14

$$m_{14} \, c_{p,14} \, (T_{14}^{n+1} - T_{14}^n) = \{(1/R_{14,1})[(T_1^{n+1} - T_{14}^{n+1}) + (T_1^n - T_{14}^n)]/2$$

$$+ \, (1/R_{14,15})[(T_{15}^{n+1} - T_{14}^{n+1}) + (T_{15}^n - T_{14}^n)]/2\} \, \Delta t \tag{3}$$

where $R_{i,j}$ is the thermal resistance between the nodes $i$ and $j$ and is given by

$$R_{i,j} = w_{ij} \, /(A_{ij}k_{ij})$$

$w_{ij}$ - distance between nodes $i$ and $j$

$A_{ij}$ - Surface area for heat transfer between nodes $i$ and $j$

$k_{ij}$ - Equivalent thermal conductivity between nodes $i$ and $j$

The above formulation yields equations which are average of the forward and backward difference equations. This Crank-Nicholson formulation provides guaranteed convergence, as well as having faster convergence characteristics.

The temperatures of all nodes are assumed to be at the specified room temperature until the time instant when the reaction starts, and the heater temperature rises to $T_1$. Equations (1)-(3) are then applied for every time step from that instant on until the end of the heating period.

At every time step $n+1$, the 14 equations for the 14 nodes have to be solved simultaneously. To enable the computations on Personal Computer, a Gauss-Seidel iterative method is employed for solving the simultaneous equations.

The average food temperature at any time instant is then calculated by finding the average temperature of the heated and the unheated portions of food.

## 4. COMPUTER PROGRAM

A computer program, PROGRAM HEATR1 is developed to implement the finite difference scheme described in Section 3. The program allows the user to input the information on the food and material properties, initial temperatures, heater temperature, time step, and heat transfer surface area through an input file, INPUT.DAT. The program has the following features:

* Documentation at every major step in the program to facilitate the incorporation of any subsequent changes.

* Nomenclature within the program code for easy reference.

* Structured for future expansion.

7

A copy of the program and the sample input data file are included in Appendixes A and B, respectively, A sample output file is given in Appendix C. Appendix D contains a user's manual illustrating the use of the computer program.

## 5. EXPERIMENTAL INVESTIGATION

An experimental investigation is undertaken for the following three reasons:

a) To obtain data for validating the numerical model described in sections 3 and 4.

b) To study the heating process and observe any clues which might be helpful in improving the numerical model.

c) To gain a practical, hands-on experience of the entire heating process to identify any aspects where improvements could be made.

For the experiments, a food pouch (MRE) was selected instead of pouches filled with water since the water pouches do not simulate the actual heating process because of a significant amount of convection occurring in them.

The thermocouples used for the heating process were specially prepared by applying a thin coating of epoxy on the exposed surface near the thermocouple junction. Care was taken as to form only a thin layer so as not to affect the transient response of the thermocouples.

The thermocouples were placed at the following locations:

i) On the two sides of the heater element between the pad and the cover.

ii) Two thermocouples between the heater cover and the food pouch.

iii) Two thermocouples on the opposite side of the food pouch.

iv) One thermocouple inside the food pouch for the specially prepared food pouches.

v) One thermocouple on the outer surface of the carton.

The output from the thermocouples was connected to a data recorder (DATASTRIP III) which was set to scan all the output channels every 20 seconds.

The experimental procedure followed is given in Appendix E.

The time-temperature data obtained by the data recorder is then used for further analysis and comparison with the numerical scheme.

Seven tests were conducted and the results and discussion are presented in the next section.

## 6. RESULTS AND DISCUSSION

### 6.1 Sensitivity Analysis

A sensitivity analysis was performed using the numerical model described in Sections 3 and 4. The purpose of the analysis is to identify the major system variables which have the greatest influence on the thermal performance of the heater. The following parameters enter directly in the performance calculations, and are varied over a wide range to study their influence.

i) Thermal resistance of the cover pad on the heater

ii) Thermal resistance of the heat loss paths to the atmosphere

9

iii) Ambient temperature

iv) Surface area of the food pouch for heat transfer

The effects of varying each of the parameter is evaluated through the thermal simulation program. The base conditions for the simulation program were:

Food material: Chili, 8. ozs.

Thermal properties of food:     $k = 0.5381$ W/m-$^{\circ}$C,

Water content 65 %

Thermal diffusivity = $1.533 \times 10^{-3}$

Ambient temperature and Initial temperature of food:

30 $^{\circ}$C and 5 $^{\circ}$C.

Delay time for starting the reaction after addition of water:

1 minute for $T_{initial} = 30\ ^{\circ}$C

3 minutes for $T_{initial} = 5\ ^{\circ}$C

Heater pad surface temperature after the start of reaction:

95 $^{\circ}$C for $T_{initial} = 30\ ^{\circ}$C

100 $^{\circ}$C for $T_{initial} = 5\ ^{\circ}$C

Surface area for heat transfer:

Heater pad surface area on one side plus 15% of that area to account for diffusion of heat along the length of the food pouch.

Heat transfer coefficient between the carton and surrounding air:                    10 W/m$^{2}$-$^{\circ}$C

### i) Thermal resistance of the cover pad

The thermal resistance of the cover pad is the only thermal resistance between the heater and the food pouch. When the cover pad is wet, its thermal resistance decreases considerably due to the presence of water. Figure 2 shows the predictions for the average temperature of the food after mixing as a function of time after starting the heating process (assuming the heating process is terminated at that time).

The two curves drawn show the effect of varying the thickness of the heater cover by a factor of 4. Solid curve shows the performance with a pad thickness of 120 microns which is currently employed. Dashed curve represents the performance with a heater pad thickness of 480 microns. The two curves are very close to each other, and it can be concluded that the heater pad thermal resistance has very little influence on the thermal performance. The thickness of the heater pad will be governed by strength and cost considerations.

### ii) Thermal resistance of heat loss path to the surroundings

The heat loss to the surroundings occurs by convective heat loss from the carton to the surrounding air by natural convection. The heat loss by this mode was calculated to be a total of 18.2 kJ from both sides of the heater . This compares to approximately 40 kJ of energy needed to heat the food from 30 $^{\circ}$C to 70 $^{\circ}$C, and a total of approximately 130 kJ released by the heating process over a 20 minute time period. The heat losses increase to 24.4 kJ when the ambient temperature is 5 $^{\circ}$C.
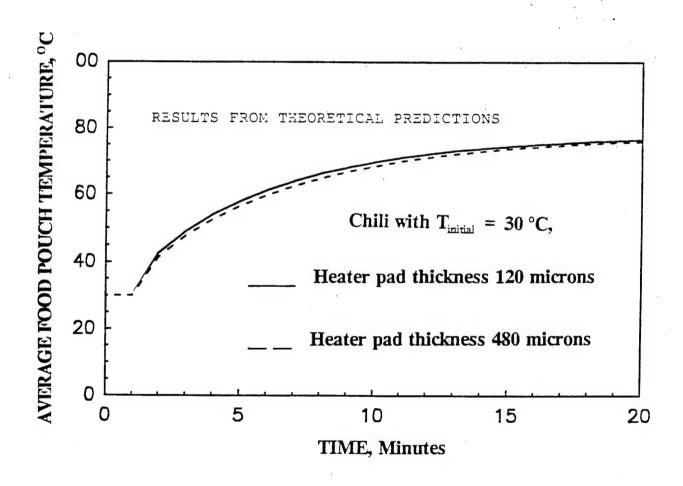
11

Figure 2. Effect of heater pad thickness on the heating performance
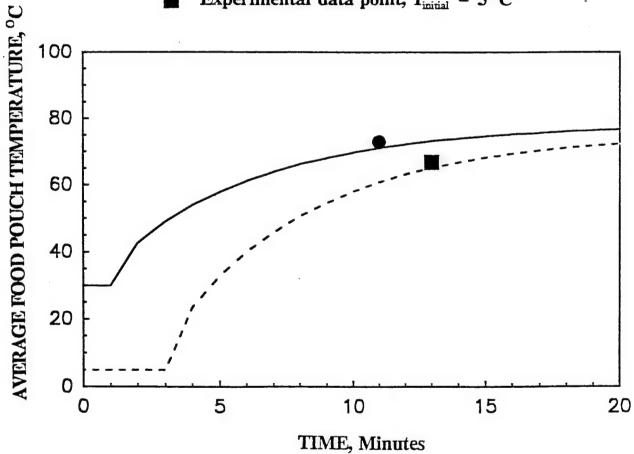
Figure 3. Effect of initial temperature on the thermal performance

There are three resistances in the thermal path for the heat losses to the surroundings. These are a) the thermal resistance of the carton, ($R=1.1 \times 10^{-3}$ °C/W), b) the thermal resistance of the polyethylene bag, ($R=7.3 \times 10^{-5}$ °C/W) and c) the thermal resistance due to convective heat transfer between the carton and the surrounding air ($R=0.1$ °C/W). It is seen that the parameters, which are under the designer's control, such as the thickness of the carton or the thickness of the bag, have very little influence on the performance.

In order to conserve energy so that a smaller heater could be utilized, it is essential to reduce the heat losses significantly. This can be done by insulating the carton. The cost benefit of this effect should be further evaluated in light of the additional weight and volume introduced by increasing the carton insulation. The carton insulation is expected to be a major parameter in the overall system optimization.

### iii) Ambient Temperature

The effect of lowering ambient temperature is seen in three different ways. Firstly, the initial temperature of the food and the heater is same as the ambient temperature, and a greater amount of thermal energy will be needed to reach the same final temperature. Secondly, the heat losses from the assembly would increase with a decrease in ambient temperature. Finally, the lower initial temperature would provide a greater temperature difference between the heater and the food since the heater surface temperature is assumed to be close to 100 °C irrespective of the initial temperature. This will make the heating process more efficient, and the thermal energy will be transferred faster into the food pouch. This model assumes that enough thermal energy is released by the heater during the heating process to maintain the increased heat transfer rate while heating the food with a lower initial temperature.

The initial waiting time before the start of the reaction is assumed to be 1 minute for $T_{initial}=30$ °C, and 3 minutes for $T_{initial}=5$ °C. Also, the heater surface temperature is assumed to be 95 °C and 100 °C respectively for $T_{initial}$ of 30 °C and 5 °C respectively.

14

Figure 3 shows the average temperature of food as a function of different heating periods for two different initial temperatures. At the end of a 10 minute heating period, the average food temperature with $T_{initial} = 30$ °C is 72.8 °C, while it is 63.1 with $T_{initial} = 5$ °C. The corresponding values at the end of 20 minute time period are 80.2 and 73.1, respectively. The temperature rise is thus seen to be faster with a lower initial temperature.

## iv) Surface area of the food pouch for heat transfer

The heat transfer rate from the heater to the food pouch is directly proportional to the surface area available for heat transfer. However, since the model is based on a one-dimensional analysis, the heat transfer in the plane of the food pouch near the edges of the heater surface will provide an additional effective area. To account for this area, a factor of 1.15 is employed to represent an effective area for heat transfer. This factor was based on comparison of the theoretical predictions with the experiment. Further discussion on this aspect is presented while discussing the experimental results.

## 6.2 Experimental Results

The theoretical development presented in Sections 3 and 4 was primarily based on the information available at the time model was developed. The assumptions made in the model therefore need to be verified in order to validate the model and gain an insight into the physics of the heating process.

Two sets of experiments were performed in which the time temperature history and the average bulk temperature at the end of a certain heating time were recorded.

Figure 3 shows the average food temperature as a function of heating time. Solid curve represents the theoretical performance as predicted by the computer program for $T_{initial} = 30$ °C. The filled circle represents the experimental data point which was obtained at the end of a 10 minute heating cycle. It can be seen that the experimental point lies close to the theoretical prediction. The dashed curve represents the theoretical
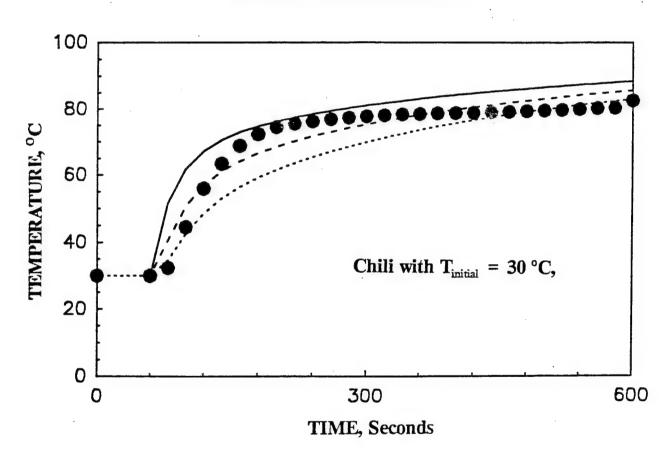
15

Figure 4. Comparison of transient thermal characteristics of food with theoretical model predictions.

performance for $T_{initial} = 5$ °C. Also shown is an experimental point, filled square, for this case. In case of $T_{initial} = 5$ °C, the model in general tended to predict a lower performance than the experimental values; the main reason being a significant amount of steam generation for the case of $T_{initial} = 30$ °C, which was not accounted by the model. Further discussion on this aspect is included in Section 6.3.

Figure 4 shows the results of an experiment with the temperature within the food pouch plotted as a function of time. The corresponding plot obtained from the theoretical model is shown in Fig. 4. The agreement between the experiment and theory is reasonable, and further fine-tuning in the thermal model is necessary to improve the agreement. This work could not be undertaken due to a limited time of six weeks available to perform the entire work.

## 6.3 Observations on the Mechanics of the Heating Process

The following observations were made during the heating process:

i) The heater surface temperature jumped in a very short time from the ambient temperature to about 95-100 °C.

ii) The heater surface temperature after the initiation of reaction was independent of the initial food pouch temperature.

iii) The initiation of the heater reaction was delayed from about 1 minute to approximately 3 minutes when the initial temperature of the food and the water were lowered from 30 °C to 5 °C.

iv) The reaction was initiated and sustained at a higher value of heat generation rate when the $T_{initial}$ was 5 °C, with the heater surface temperature maintained at 100 °C (as against 95 °C for $T_{initial} = 30$ °C). A possible explanation for this may be that with the lower heater temperature, the heater had a longer time to get soaked, and a

17

larger amount of magnesium was able to participate in the reaction.

v) A considerable amount of steam was generated and the heat-transfer process was no longer restricted through the interface between the heater and the food pouch. The steam flowed through the bag and condensed during its passage as it came in contact with the colder parts of the food pouch above the heater. Steam also was seen to condense in the portion of the bag which was wrapped around the food pouch. The heat transfer coefficient with condensing steam being very high, the actual heating process in all experiments was found to be more efficient than the theoretical predictions based on the interface area alone for heat transfer. This fact needs to be further quantified and considered while designing heating systems for other configurations.

## 7. CONCLUSIONS

A numerical model is developed to predict the transient thermal performance of Flameless Ration Heaters. The model predicts the temperature at various locations in the food as well as the average temperature of the food at the end of a given time period. Experiments were conducted to validate the theoretical model. Good agreement was observed between the theoretical predictions and the experimental values.An additional heat transfer mechanism was observed during the experimentation. When the initial temperature of the heater and the water was lowered to 5°C, the heater reaction was initiated after 3 minutes and a rapid steam generation was observed. This behavior was initiated after 3 minutes and a rapid steam generation was observed. This behavior was not expected on the basis of information available on the heaters. Since the heat transfer mechanism is altered significantly, the simulation model needs to modified further. Additionally, the rate of heat generation in the heater as a function of time needs to be determined accurately.

# 8. SCOPE FOR FUTURE WORK

The work performed on the simulation and experimentation on the Flameless Ration Heaters provided valuable information in understanding the basic mechanisms of heat transfer involved in heating an MRE. The knowledge gained can be utilized in further refining the model and optimizing its performance. Also, the model provides helpful directions in designing the FRH based systems for heating other configurations such as individual meal trays.

Specifically, the following work may be undertaken in future.

i) The theoretical model developed in the present work could be modified to account for the steam generation and additional heat transfer resulting from the contact of the steam and hydrogen gas with additional surfaces of MRE pouch.

ii) The experience and knowledge gained in this project through the theoretical and experimental work on the Flameless Ration Heaters could be extended to develop efficient heating system design for other configurations including Individual Meal Trays and Tray Packs.

iii) The experimental procedure followed here could be further refined to arrive at a standardized testing procedure for conducting quick and accurate quality control checks on the Flameless Ration Heaters.

# 9. REFERENCES

Burden, R.L., NUMERICAL ANALYSIS, Second Edition, Prindle, Weber and Schmidt Publishers, pp. 528.

BLANK PAGE

# APPENDICES

BLANK PAGE

# APPENDIX A

## COMPUTER PROGRAM

```
          PROGRAM    HEATER
C THIS   PROGRAM   SIMULATES    THE   PERFORMANCE    OF  THE   MRE   HEATER
C THE    WORK   IS  PERFORMED     BY  DR.   SATISH   G.  KANDLIKAR    FOR   THE
C US  ARMY   LABORATORY    AT  NATICK,    MA,  DURING   SUMMER    1990.
C
C NOMENCLATURE
C
C BH  -  WIDTH   OF  THE   HEATER,    M
C BF  -  WIDTH   OF  THE   FOOD   BLOCK   IN  THE   POUCH,   M
C CH  -  LENGTH   OF  THE   HEATER,    M
C CF  -  LENGTH   OF  THE   FOOD   BLOCK   IN  THE   POUCH,    M
C CPB  -  SPECIFIC   HEAT   OF  BAG   MATERIAL,    J/KG-K
C CPC  -  SPECIFIC   HEAT   OF  COVER   MATERIAL,    J/KG-K
C CPF  -  SPECIFIC   HEAT   OF  FOOD.   J/KG-K
C CPH  -  SPECIFIC   HEAT   CF  HEATER,   J/KG-K
C CPP  -  SPECIFIC   HEAT   OF  POUCH   MATERIAL,    J/KG-K
C CPW  -  SPECIFIC   HEAT   OF  WATER,    J/KG-K
C
C CP(25)   -  SPECIFIC   HEAT   OF  MATERIAL   AT  THE   INDIVIDUAL   NODES,   J/KG-K
C HAMB  -  HEAT   TRANSFER   COEFFICIENT    ON  THE   CARTON   SURFACES   EXPOSED   TO
C          AMBIENT   AIR,   W/M**2-C
C HFG  -  LATENT   HEAT   OF  STEAM,    J/KG
C K(25)   -  THERMAL   CONDUCTIVITY    OF  MATERIAL   AT  THE   INDIVIDUAL   NODES,
C          W/M-C
C KB  -  THERMAL   CONDUCTIVITY    OF  BAG   MATERIAL,    W/M-C
C KC  -  THERMAL   CONDUCTIVITY    OF  COVER   MATERIAL,    W/M-C
C KF  -  THERMAL   CONDUCTIVITY    OF  FOOD,   W/M-C
C KH  -  THERMAL   CONDUCTIVITY    OF  HEATER   MATERIAL,    W/M-C
C KP  -  THERMAL   CONDUCTIVITY    OF  POUCH   MATERIAL,   W/M-C
C KPW  -  THERMAL   CONDUCTIVITY    OF  WATER,   W/M-C
C
C MS  -  AMOUNT   OF  STEAM   GENERATED,    KG
C MASS(25)   -  MASS   PER   UNIT   AREA   AT  DIFFERENT    NODES,   KG/M**2
C N  -  NUMBER   OF  NODES   IN  THE   FOOD
C QGEN  -  HEAT   GENERATION    RATE,   W/M**3
C R(25,2)   -  CONTACT   RESISTANCE    ON  THE   TWO   SIDES   OF  A NODE,   C/W
C          R(N,1)   RESISTANCE   BETWEEN    THE   NODE   AND   ADJACENT   LOWER
C                   NUMBERED    NODE
C          R(N,2)   CONTACT   RESISTANCE   BETWEEN    THE   NODE   AND   ADJACENT
C                   HIGHER   NUMBERED    NODE
C RHO(25)   -  DENSITY   OF  MATERIAL   AT  THE   INDIVIDUAL   NODES,   KG/M**3
C RHB  -  DENSITY   OF  BAG   MATERIAL,    KG/M**3
C RHC  -  DENSITY   OF  COVER   MATERIAL,    KG/M**3
C RHH  -  DENSITY   OF  HEATER,   KG/M**3
C RHP  -  DENSITY   OF  POUCH   MATERIAL,    KG/M**3
C RHF  -  DENSITY   OF  FOOD,   KG/M**3
```

```
C RHW  -  DENSITY    OF  WATER,    KG/M**3
C T(25,600)   -  TEMPERATURE     AT  50  NODES   AT  600  TIME   STEPS
C TAMB  -  AMBIENT    TEMPERATURE,     C
C TSTART   -  TIME   ELAPSED   BEFORE   THE  HEATER   REACTION   IS  INITIATED,    SEC
C TSTEP  -  TIME   STEP,   SEC
C W(25)  -  WIDTH   OF  INDIVIDUAL   NODES,   M
C WB  -  THICKNESS   OF  BAG,   M
C WC  -  THICKNESS   OF  COVER,   M
C WH  -  THICKNESS   F  HEATER,   M
C WP  -  THICKNESS   OF  POUCH,   M
C WF  -  THICKNESS   OF  FOOD,   M
C WG  -  THICKNESS   OF  WATER   GAP,   M
C
C CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
        REAL   K,  MS,  KC,  KH,  KP,  KF,  KG,  MASS
        CHARACTER*1    RES
        DIMENSION    CP(25),   D(25,2),   K(25),   R(25),   RHO(25),
     1               TOLD(25),   TNEW(25),   TNEWPR(25),   W(25),   MASS(25),
     2  TAVE(30)
        COMMON/PAR/BH,     BF,  CPB,  CPC,  CPH,  CPK,  CPP,  CPF,  CPW,  ERRLMT,
     1  HAMB,  HFG,  KB,  KC,  KH,  KK,  KP,  KF,  KW,  N,  QGEN,
     2  RHB,  RHC,  RHH,  RHK,  RHP,  RHF,  RHW,  TAMB,  TSTEP,  WB,  WC,  WH,
     3  WK,  WP,  WF,  WG,  THEATR,  TIMEMAX,  TSTART
C
C INPUT   THE   VALUES   OF  ALL  GEOMETRICAL   AND  THERMAL   VARIABLES   THROUGH
C AN  INPUT   SUBROUTINE.
C
        CALL   INPUT
C
C ESTIMATE   THICKNESS   AND  AVERAGE   THERMAL   PROPERTIES   OF  EACH   NODE
C
        MASS(1)   = WH*RHH
        CP(1)  = CPH
        R(1)  = 1
C
        MASS(2)   = WC*RHC   + WG*RHW   + WP*RHP
        CP(2)  = (WC*RHC*CPC   + WG*RHW*CPW   + WP*RHP*CPP)/
     1           (WC*RHC   + WG*RHW   + WP*RHP)
        R(2)  = WC/KC   + WG/KW   + WP/KP
        D(2,1)   = TSTEP/(2.0*MASS(2)*CP(2)*(R(2)/2.0))
        D(2,2)   = TSTEP/(2.0*MASS(2)*CP(2)*((R(2)+R(3))/2.0))
C
        DO  100   I=3,2+N
        MASS(I)   = (WF/N)*RHF
        CP(I)  = CPF
```

27

```fortran
          R(I)    = (WF/N)/KF
          R(I+1)=R(I)
          D(I,1)    = TSTEP/(2.0*MASS(I)*CP(I)*(R(I)+R(I-1))/2.0)
          D(I,2)    = TSTEP/(2.0*MASS(I)*CP(I)*(R(I)+R(I+1))/2.0)
  100     CONTINUE
C
          MASS(N+3)    = WP*RHP   + WG*RHW   + WB*RHB   + WK*RHK
          CP(N+3)    = (WP*RHP*CPP    + WG*RHW*CPW   + WB*RHB*CPB    + WC*RHC*CPC)/
     1               (WP*RHP   + WG*RHW   + WB*RHB   + WK*RHK)
          R(N+3)    = WP/KP   + WG/KW   + WB/KB   +WK/KK
          D(N+3,1)    = TSTEP/(2.0*MASS(N+3)*CP(N+3)*(R(N+3)+R(N+2))/2.0)
          D(N+3,2)    = TSTEP/(2.0*MASS(N+3)*CP(N+3)*(R(N+3)/2.0+
     1   1.0/HAMB))
C
          MASS(N+4)    = WC*RHC   + WG*RHW   + WB*RHB   + WC*RHC
          CP(N+4)    = (WC*RHC*CPC    + WG*RHW*CPW   + WB*RHB*CPB    + WC*RHC*CPC)/
     1               (WC*RHC   + WG*RHW   + WB*RHB   + WC*RHC)
          R(N+4)    = WC/KC   + WG/KW   + WB/KB   + WC/KC
          D(N+4,1)    = TSTEP/(2.0*MASS(N+4)*CP(N+4)*(R(N+4)/2.0))
          D(N+4,2)    = TSTEP/(2.0*MASS(N+4)*CP(N+4)*(R(N+4)/2.0+
     1   1.0/HAMB))
C
C WRITE    TITLE    FOR   THE   TIME   TEMPERATURE    RESULTS
C
          WRITE(6,51)
          WRITE(10,51)
  51      FORMAT(5X,'TIME     IN   SECONDS   AND   TEMPERATURES    AT   14   NODES   ARE   AS   F
     1OLLOWS:')
C
C SUPPLY    INITIAL    VALUES   OF   T   AT   TIME=0   UP   TO   TIME=60   SEC   SINCE
C NO   REACTION    OCCURS   FOR   THE   FIRST   TSTART   SECONDS
C
          TIME=0.0
          DO  200   I=1,N+4
          TOLD(I)    = TAMB
  200     CONTINUE
          WRITE(10,21)TIME,(TOLD(I),I=1,14)
  21      FORMAT(2X,F5.1,3X,14(F7.3))
          TIME=TSTART
          WRITE(10,21)TIME,(TOLD(I),I=1,14)
          WRITE(6,21)TIME,(TOLD(I),I=1,14)
C
C INCREMENT    THE   TIME   STEP   AND   EVALUATE    ALL   T'S   BY   GAUSS-SIEDEL
C ITERATION    TECHNIQUE    FOR   NEXT   9 MINUTES.
C
          TOLD(1)    = THEATR
```

28

```fortran
          NSTEP=(TIMEMAX-TSTART)/TSTEP
C
C SET   HEAT   LOSSES   EQUAL   TO   ZERO
C
          QLOSS1=0.0
          QLOSS2=0.0
          DO   1000   ISTEP=1,NSTEP
          TIME=TIME+TSTEP
C
C SUPPLY   INITIAL   GUESSES   FOR   ALL   TEMPERATURES
C
          DO   300   I=1,N+4
          TNEW(I)    = TOLD(I)
  300     CONTINUE
C
C ITERATE   FOR   A   GIVEN   TIME   STEP
C
          DO   400   ITER=1,100
          DO   700   I=1,N+4
          TNEWPR(I)    = TNEW(I)
  700     CONTINUE
          TNEW(2)=(TOLD(2)+D(2,1)*(TNEW(1)+TOLD(1)-TOLD(2))
         1           +D(2,2)*(TNEW(3)+TOLD(3)-TOLD(2)))/(1.0+D(2,1)+D(2,2))
          DO   500   I=3,N+2
          TNEW(I)=(TOLD(I)+D(I,1)*(TNEW(I-1)+TOLD(I-1)-TOLD(I))
         1           +D(I,2)*(TNEW(I+1)+TOLD(I+1)-TOLD(I)))/
         1             (1.0+D(I,1)+D(I,2))
  500     CONTINUE
          I=N+3
          TNEW(I)=(TOLD(I)+D(I,1)*(TNEW(I-1)+TOLD(I-1)-TOLD(I))
         1           +D(I,2)*(2.0*TAMB-TOLD(I)))/
         1             (1.0+D(I,1)+D(I,2))
          I=N+4
          TNEW(I)=(TOLD(I)+D(I,1)*(TNEW(1)+TOLD(1)-TOLD(I))
         1           +D(I,2)*(2.0*TAMB-TOLD(I)))/
         1             (1.0+D(I,1)+D(I,2))
          ERRMAX=0.0
          DO   600   I=1,N+4
          ERR=ABS(TNEWPR(I)-TNEW(I))
          IF(ERR.GT.ERRMAX)ERRMAX=ERR
  600     CONTINUE
          IF(ERRMAX.LT.ERRLMT)GO           TO   610
  400     CONTINUE
          WRITE(10,22)ISTEP
          WRITE(6,22)ISTEP
  22      FORMAT(//,2X,'ITERATION           NOT   CONVERGED   AT   ISTEP=',I4,//)
```

29

```
610         CONTINUE
            I1  =  TIME/20.0
            I2  =  (TIME-TSTEP)/20.0
            IF(I1.GT.I2)GO         TO   620
            GO   TO   630
620         CONTINUE
            WRITE(10,21)TIME,(TNEW(I),I=1,14)
            WRITE(6,21)TIME,(TNEW(I),I=1,14)
630         CONTINUE
C            WRITE(6,21)TIME,(TNEW(I),I=1,14)
C           WRITE(6,25)
C25         FORMAT(2X,'ENTER        N  IF  YOU  WANT  TO  STOP,  ANY  OTHER  KEY  TO  CONTINU
C     1E')
C           READ(5,26)RES
C26         FORMAT(A1)
C           IF(RES.EQ.'N')GO         TO   1010
            I1=TIME/60.0
            I2=(TIME-TSTEP)/60.0
            IF(I1.GT.I2)THEN
                IJ=(TIME/60)
                TAVE(IJ)=0.0
                DO   800    I=3,N+2
                TAVE(IJ)=TAVE(IJ)+TNEW(I)
800           CONTINUE
                TAVE(IJ)     =  TAVE(IJ)/N
                TAVE(IJ)     =  (TAVE(IJ)*BH      +  TAMB*(BF-BH))/BF
            ENDIF
            DO   900    I=1,N+4
            TOLD(I)=TNEW(I)
900         CONTINUE
            QLOSS1=QLOSS1+(6.5*3.5*2.54**2/1E4)*HAMB*(TNEW(13)-TAMB)*TSTEP
            QLOSS2=QLOSS2+(6.5*3.5*2.54**2/1E4)*HAMB*(TNEW(14)-TAMB)*TSTEP
1000        CONTINUE
1010        CONTINUE
            IJMAX=TIMEMAX/60
            WRITE(6,31)
            WRITE(10,31)
            DO   810   IJ=1,IJMAX
            WRITE(10,32)IJ,TAVE(IJ)
            WRITE(6,32)IJ,TAVE(IJ)
31          FORMAT(2X,//,'TIME        IN  MINUTES        AVERAGE   FOOD   TEMPERATURE,      C',/)
32          FORMAT(8X,I2,14X,F6.1)
810         CONTINUE
            QLOSS1=QLOSS1/1000.0
            QLOSS2=QLOSS2/1000.0
            QLOSS=QLOSS1+QLOSS2
```

30

```
          WRITE(10,23)QLOSS1,QLOSS2,QLOSS
          WRITE(6,23)QLOSS1,QLOSS2,QLOSS
   23     FORMAT(//,5X,'    HEAT   LOSSES    IN  KILOJOULES     FROM    THE   CARTON    ARE-',/,
        2 15X,'TOP    SIDE',8X,'BOTTOM      SIDE',8X,'TOTAL',/,15X,F10.2,8X,F10.2,
        3 8X,F10.2)
          END
C END  OF  PROGRAM    HEATER
C CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
          SUBROUTINE    INPUT
C
C SUBROUTINE   INPUT   READS   THE   VALUES   OF  GEOMETRICAL    AND   THERMAL
C PARAMETERS    CONTAINED    IN  COMMON/PAR/
C
          REAL   K,  MS,  KB,  KC,  KH,  KK,  KP,  KF,  KW
          COMMON/PAR/BH,     BF,  CPB,  CPC,  CPH,  CPK,  CPP,  CPF,  CPW,  ERRLMT,
        1 HAMB,  HFG,  KB,  KC,  KH,  KK,  KP,  KF,  KW,  N,  QGEN,
        2 RHB,  RHC,  RHH,  RHK,  RHP,  RHF,  RHW,  TAMB,  TSTEP,  WB,  WC,  WH,
        3 WK,  WP,  WF,  WG,  THEATR,  TIMEMAX,  TSTART
          READ(20,*)BH,BF
          READ(20,11)I
   11     FORMAT(I1)
          READ(20,*)    CPB,CPC,CPH,CPK,CPP,CPF,CPW
          READ(20,11)I
          READ(20,*)    ERRLMT,HAMB,HFG
          READ(20,11)I
          READ(20,*)    KB,KC,KH,KK,KP,KF,KW
          READ(20,11)I
          READ(20,12)N
   12     FORMAT(2X,I2)
          READ(20,11)I
          READ(20,*)RHB,RHC,RHH,RHK,RHP,RHF,RHW
          READ(20,11)I
          READ(20,*)TAMB,    TSTEP
          READ(20,11)I
          READ(20,*)WB,    WC,  WH,  WK,  WP,  WF,  WG
          READ(20,11)I
          READ(20,*)THEATR,    TIMEMAX
          READ(20,11)I
          READ(20,*)TSTART
C
C ERROR   MESSAGES
C
C MESSAGE   1,  INPUT   TEMPERATURE    BELOW   0 C
C
   30     CONTINUE
```

31

```
          IF(TAMB.LE.0.0)THEN
             WRITE(6,31)
31           FORMAT(2X,'FATAL      ERROR    # 10,  INPUT   TEMPERATURE    BELOW    FREEZING
     1TEMPERATURE',/,2X,'PLEASE         ENTER   A  VALUE   ABOVE   0  C  TO  CONTINUE,
     2OR    ENTER   1000    TO  EXIT')
             READ(6,*)TAMB
             IF(TAMB.EQ.1000)      GO  TO  1000
             GO   TO  30
          ENDIF
40        CONTINUE
          IF(TAMB.GE.100.0)THEN
             WRITE(6,41)
41           FORMAT(2X,'FATAL      ERROR   # 20,  INPUT   TEMPERATURE    ABOVE    BOILING   TEM
     1PERATURE',/,2X,'PLEASE         ENTER   A  VALUE   BELOW    100  C  TO  CONTINUE,      .OR
     2ENTER    1000    TO  EXIT')
             READ(6,*)TAMB
             IF(TAMB.EQ.1000)      GO  TO  1000
             GO   TO  40
          ENDIF
1000      CONTINUE
          END
C
C END   OF   SUBROUTINE      INPUT
```

# APPENDIX B

## SAMPLE INPUT DATA FILE

# SAMPLE INPUT DATA FILE

```
    0.140              0.178
1 HEATER    LENGTH    FOOD   LENGTH
         2010.0   1340.0   2930.0   1340.0   2010.0   3200.0   4180.0
1        CPB      CPC      CPH      CPK      CPP      CPF      CPW
    0.01         10.0     2.4E6
1 ERRLMT        HAMB       HFG
         0.3     0.5      0.68        0.2      0.3      0.58     0.68
1        K-BAG   K-COVER   K-HEATER    K-CARTON  K-POUCH   K-FOOD   K-WATER
    10
1 NUMBER   OF   NODES   IN   FOOD
    2200.0       930.0    1300.0    160.0       2200.0    900.0     1000.0
1   RH-BAG       RH-COVER   RH-HEATER   RH-CARTON   RH-POUCH   RH-FOOD   RH-WATER
    30.0     1.0
1 TAMB     TSTEP
         0.000022    0.00012    0.002     0.00022   0.00008   0.0125   0.00005
1        W-BAG      W-COVER     W-HEATER    W-CARTON   W-POUCH   W-FOOD   W-WATER   GAP
         95.0       600.0
1        THEATR      MAXIMUM    TIME    IN   SECONDS
    60.0
1   TIME   ELAPSED   BEFORE   THE   HEATER   REACTION   IS   INITIATED,   SECONDS
```

)

# APPENDIX C

# SAMPLE OUTPUT FILE

# SAMPLE OUTPUT FILE

```
   TIME   IN  SECONDS   AND   TEMPERATURES     AT  14  NODES  ARE  AS  FOLLOWS:
    0.0       30.000   30.000   30.000   30.000   30.000   30.000   30.000   30.000   30.000   30.000
30.000   30.000   30.000   30.000
   60.0       30.000   30.000   30.000   30.000   30.000   30.000   30.000   30.000   30.000   30.000
30.000   30.000   30.000   30.000
   80.0       95.000   81.786   68.671   51.835   40.778   34.670   31.790   30.611   30.188   30.052
30.013   30.004   30.003   94.844
  100.0       95.000   85.365   75.749   61.918   50.757   42.561   37.071   33.705   31.810   30.829
30.365   30.180   30.159   94.845
  120.0       95.000   87.043   79.098   67.212   56.918   48.553   42.173   37.603   34.530   32.599
31.492   30.971   30.906   94.845
  140.0       95.000   88.070   81.147   70.587   61.108   53.004   46.404   41.288   37.528   34.934
33.308   32.486   32.370   94.845
  160.0       95.000   88.782   82.569   72.981   64.192   56.450   49.899   44.589   40.488   37.512
35.558   34.532   34.371   94.845
  180.0       95.000   89.316   83.636   74.805   66.601   59.237   52.858   47.543   43.317   40.160
38.031   36.884   36.685   94.845
  200.0       95.000   89.740   84.484   76.271   68.575   61.582   55.431   50.218   45.997   42.787
40.584   39.374   39.142   94.845
  220.0       95.000   90.093   85.190   77.502   70.256   63.617   57.721   52.668   48.528   45.342
43.129   41.893   41.631   94.845
  240.0       95.000   90.397   85.797   78.569   71.729   65.429   59.796   54.933   50.916   47.798
45.612   44.374   44.085   94.845
  260.0       95.000   90.664   86.331   79.514   73.046   67.066   61.695   57.033   53.161   50.137
48.001   46.775   46.461   94.845
  280.0       95.000   90.905   86.814   80.369   74.244   68.566   63.450   58.994   55.276   52.359
50.285   49.075   48.739   94.845
  300.0       95.000   91.126   87.256   81.154   75.348   69.955   65.085   60.831   57.270   54.463
52.453   51.267   50.910   94.845
  320.0       95.000   91.331   87.664   81.882   76.373   71.250   66.615   62.556   59.150   56.454
54.511   53.348   52.972   94.845
  340.0       95.000   91.521   88.045   82.559   77.330   72.461   68.049   64.179   60.922   58.334
56.458   55.319   54.925   94.845
  360.0       95.000   91.699   88.400   83.193   78.226   73.597   69.397   65.706   62.592   60.109
58.298   57.183   56.771   94.845
  380.0       95.000   91.865   88.733   83.787   79.067   74.664   70.664   67.143   64.166   61.784
60.035   58.943   58.515   94.845
  400.0       95.000   92.022   89.046   84.346   79.857   75.667   71.857   68.497   65.649   63.363
61.673   60.604   60.161   94.845
  420.0      .95.000   92.169   89.340   84.871   80.601   76.612   72.980   69.773   67.048   64.852
63.219   62.171   61.713   94.845
```

| 440.0 | 95.000 | 92.307 | 89.617 | 85.365 | 81.301 | 77.501 | 74.038 | 70.975 | 68.366 | 66.256 |
| 64.677 | 63.649 | 63.178 | 94.845 | | | | | | | |
| 460.0 | 95.000 | 92.438 | 89.877 | 85.830 | 81.960 | 78.339 | 75.035 | 72.107 | 69.609 | 67.580 |
| 66.051 | 65.042 | 64.558 | 94.845 | | | | | | | |
| 480.0 | 95.000 | 92.561 | 90.123 | 86.269 | 82.581 | 79.128 | 75.974 | 73.175 | 70.780 | 68.827 |
| 67.347 | 66.356 | 65.860 | 94.845 | | | | | | | |
| 500.0 | 95.000 | 92.676 | 90.354 | 86.682 | 83.166 | 79.872 | 76.859 | 74.181 | 71.884 | 70.003 |
| 68.568 | 67.594 | 67.087 | 94.845 | | | | | | | |
| 520.0 | 95.000 | 92.785 | 90.572 | 87.071 | 83.718 | 80.573 | 77.693 | 75.129 | 72.924 | 71.112 |
| 69.719 | 68.761 | 68.244 | 94.845 | | | | | | | |
| 540.0 | 95.000 | 92.888 | 90.777 | 87.438 | 84.237 | 81.233 | 78.480 | 76.023 | 73.905 | 72.157 |
| 70.804 | 69.862 | 69.334 | 94.845 | | | | | | | |
| 560.0 | 95.000 | 92.985 | 90.971 | 87.784 | 84.727 | 81.856 | 79.221 | 76.866 | 74.829 | 73.142 |
| 71.827 | 70.899 | 70.362 | 94.845 | | | | | | | |
| 580.0 | 95.000 | 93.076 | 91.153 | 88.109 | 85.189 | 82.443 | 79.919 | 77.659 | 75.700 | 74.070 |
| 72.791 | 71.877 | 71.331 | 94.845 | | | | | | | |
| 600.0 | 95.000 | 93.162 | 91.325 | 88.416 | 85.624 | 82.996 | 80.577 | 78.408 | 76.521 | 74.945 |
| 73.700 | 72.798 | 72.244 | 94.845 | | | | | | | |

TIME  IN  MINUTES          AVERAGE  FOOD  TEMPERATURE,      C

| TIME IN MINUTES | AVERAGE FOOD TEMPERATURE, C |
|---|---|
| 1 | .0 |
| 2 | 42.7 |
| 3 | 49.1 |
| 4 | 54.0 |
| 5 | 57.9 |
| 6 | 61.2 |
| 7 | 63.9 |
| 8 | 66.2 |
| 9 | 68.1 |
| 10 | 69.7 |

HEAT  LOSSES  IN  KILOJOULES  FROM  THE  CARTON  ARE-

| TOP SIDE | BOTTOM SIDE | TOTAL |
|---|---|---|
| 1.74 | 5.14 | 6.88 |

BLANK PAGE

# APPENDIX D

## USER'S GUIDE FOR COMPUTER PROGRAM

## USER'S GUIDE FOR COMPUTER PROGRAM

The computer program to simulate the transient thermal performance of the Flameless Ration Heater for heating an MRE pouch is available in an executable file called HEATER.EXE. A separate input file called INPUT.DAT is required to run the program. Although a user will not need the source code FORTRAN program called HEATER.FOR, it is included in the disk provided, and a listing of the program is given in APPENDIX A.

Following steps may be followed to run the program.

Step 1 -    Using any ASCII editor, make the necessary changes in the input file INPUT.DAT to incorporate the geometrical conditions, food and material properties and the time duration for the heating process.

Step 2 -    Make sure that the files HEATER.EXE and INPUT.DAT are in the same subdirectory or on the same floppy disk. Enter that subdirectory or floppy disk as your screen prompt.

Step 3 -    At the screen prompt, enter "HEATER", and press RETURN key.

Step 4 -    The computer will ask for the name of UNIT 20. Enter the name of the input file, INPUT.DAT and press ENTER key.

Step 5 -    The computer will ask for the name of UNIT 10 which is an output file. Enter any name such as OUTPUT.OUT and press ENTER key.

WARNING: Any existing file with the same name as UNIT 20 name, OUTPUT.DAT in the above example will be erased and overwritten by the output from the program.

40

**Step 6 -** The output of the program is in OUTPUT.OUT file which can be printed using the PRINT OUTPUT.DAT command.

**Step 7 -** You may rerun the program by following steps 1 through 6.

BLANK PAGE

# APPENDIX E

## EXPERIMENTAL PROCEDURE

# EXPERIMENTAL PROCEDURE

The procedure followed while conducting the experiments is described below.

## Preparation

Step 1.  Place the food pouch in a refrigerator or at any other place to attain the desired initial temperature.  Allow at least an hour in the controlled temperature environment before conducting a test.  In case of the tests with the initial temperature as the room temperature, keep the food pouches in a room where there are no significant temperature changes (less than 1 C) for at least one hour prior to conducting experiments.

Step 2.  Place a bottle containing clean water in the controlled temperature environment to attain the desired initial temperature.

Step 3.  Keep a beaker handy to measure the required amount of water needed to start the chemical reaction in the heater.

Step 4.  Start the data acquisition system and make sure that it is functioning properly.

Step 5.  Label the thermocouples and connect them in the corresponding slots in the data acquisition system.

## Conducting Experiment

Step 4.  Weigh the heater pad.

Step 5.  Instrument the heater pad with two thermocouples located on each side of

the pad between the pad and the cover, and two thermocouples each on the outer surfaces of the cover.

Step 6. Place the heater pad in the bag with the thermocouple wires coming out along one of the corner edges of the bag. Make sure that the edge coated with adipic acid is toward the bottom of the bag.

Step 7. Note all the thermocouple numbers and their corresponding locations.

Step 8. Take out the food pouch from a refrigerator if it is cooled prior to heating process, or from a place where it is kept to attain a certain initial temperature. Place it immediately in the bag on one side of the heater making sure that the two thermocouples on the outer cover of the heater are firmly in place.

Step 9. Start the data acquisition system.

Step 10. Take out the water bottle from the refrigerator or the controlled temperature enclosure, and measure 2 ozs. in a beaker.

Step 11. Raise the heater pad and the food pouch above the water level markings on the bag and pour 2 ozs. of water in the bag.

Step 12. Fold the bag over and lay it flat on a horizontal surface for about 1 minute while inserting it in a cardboard carton.

Step 13. Raise the bag about 15 degrees and rest it on a support so that the water is contained near the lower end of the bag.

Step 14. Run the test for the desired length of time while recording the thermocouple outputs every 20 seconds.

Step 15. At the end of the desired time period (5, 10 or 15 minutes), carefully remove the food pouch from the carton and the bag and knead it quickly to mix the food so that it attains an average temperature. Record the average temperature by inserting a thermocouple inside the pouch.

Step 16. Stop the data acquisition system, and remove all thermocouple connections from the heater and pouch.

Step 17. Discard the food, heater bag with heater, and carton.